THE MODEL OF INERTIAL NAVIGATION SYSTEM ON BASE OF MEMS SENSORS FOR UNMANNED AERIAL VEHICLES

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Abstract. Nowadays in the navigation applications the use of autonomous vehicles is preferred. In the atmosphere condition and for physical environmental impacts there occurs the short-term disappearance of GPS signals. Because of the high durability of inertial navigation system (INS) again obstacles it becomes possible to provide reliable flights in high intensive noisy condition. In this article many issues have been discussed, including the structure, functioning principles, advantages and disadvantages of the gimbaled and strapdown INS, and the main reasons, conditioning the importance of this system. In the work there has been proposed the model of INS on the base of MEMS sensors with optimized parameters for small-sized unmanned aerial vehicles.

Аннотация. В настоящее время в навигационных системах предпочитается использование автономных транспортных средств. Из-за атмосферных условий и физической среды наблюдается исчезновение коротковременных сигналов GPS. Помехоустойчивость инерциальной навигационной системы (ИНС) очень высока, поэтому надежность полетов обеспечивается даже при условиях высокоинтенсивных шумов. В данной статье рассмотрены вопросы по принципу работы, структуре, преимуществе и недостатке платформенных и бесплатформенных ИНС и показаны основные причины, подтверждающие важности использование этих систем. В работе предложена модель инерциальной навигационной системы (ИНС) на основе МЭМС датчиков с оптимизированными параметрами для малогабаритных беспилотных летательных аппаратов.

Key words: unmanned aerial vehicle, gyroscope, roll, pitch.

Ключевые слова: беспилотный летательный аппарат, гироскоп, крен, тангаж, курс.

Introduction. It is difficult to imagine the modern world without modern navigation system, i.e., without inertial sensors, which are covering all aspects of human life. The creation and the investigation of these types of sensors has led to the use of modern navigational complexes as a part of the INS [1]. The preparation of micromechanical sensors and inertial measurement unit (IMU) for its complex constructive structure, small sizes require high technologies from developed industrialized countries.

The actuality of the theme. Autonomous vehicles, seen as the future of many technology advances, have become the critical element for as to countries, which are handled the technology with its advanced specifications and capabilities. This issue is a great importance to us in terms of applying to various industries.

Last years, INS rockets have been improved from the electromechanical instruction to semi conductor devices, which are used in many modern vehicles. The speed of this improvement has been increased during the 1960s ballistic rocket program, and there was a great need for the high-precision autonomous navigation system [2]. If satellite and radio communication systems are intentionally interrupted in the INS, the control unit will be screened with the INS and the control will be held with internal program then the hostile will not be able to stop its operation. The INS, which develops by micromechanical inertial sensors, that have been advancing rapidly without external impacts over last 20 years, it has become an important part of flight apparatuses, ships, missles specialists as a standard part of civilian and military navigation systems nowadays. It has been revealed that especially, in recent years autonomous systems are being developed and achieved high results by the application of the systems, developed in this form to different vehicles. This can be attributed to the development of auto transportations of cargoes at ports, the successful use of non-pilot submarine vehicles for the various purposes, and the development of inter-city and internal-city non-pilot transportable vehicles or bomb disposal robots [3].

The object of the work is the definition of perspective development directions of autonomous navigation systems and the construction of the model of inertial navigation system with optimized parameters for small-sized unmanned aerial vehicles.

The problem solution ways and its discussion. In the future by the INS algorithm, which will be written in the framework of this research work, there have been supposed the receipt of information like as the position, speed by the assessment of measurements, and besides, on the base of conceptual definitions, the minimization of faults by using the Kalman filter by the construction of the fault model of this system. It is expedient to obtain measurements, which are the base for INS, from inertial measurement modules, and to elaborate a measuring block that works along with inertial sensors, which present the speed of the angle and the linear acceleration information. In the aviation on managing the flying devices the navigation systems, including the inertial navigation system, are vital practically important. Though the development of satellite and surface radio navigation systems narrows INS application fields, but in many cases the use of INS is indispensable and important. It is very possible for the provision of flights in high-intensive noisy condition. Because of the high durability of the INS to obstacles, high-intensity noise can be safely maintained. Recently, there have been created new types of inertial devices with gyroscopes and accelerometers, made on the base of low-cost, as well as small-sized microelectromechanical technology (MEMS) [4]. However yet on the point of view of accuracy on using the gyroscope and accelerometers in the composition of inertial systems there arises a need to implement the correction of the information.

By the wide application of systems like as GPS, GLONASS, Galileo in the definition of the speed and coordinates the accuracy is ensured considerably [5]. If other short-term signals are lost in satellite navigation receiver, other correction information may be used. The basic operating mode for complex navigation systems is considered the integration of inertial and satellite systems. The importance of two integrating navigational systems, that are so different from each other, is explained by the principal differential faults in each of them. In fact, many navigation tasks can only be done with the help of GPS. Inertial sensors are used only for the stabilization and control. However, GPS's vulnerability to barriers may indicate the importance of navigation sensors, and also navigation sensors can be used in areas, where GPS is not applicable (e.g. any object, tunnel or carve).

Due to faults in components (gyroscopes and accelerometers) the INS cannot fully reflect the position. Those faults cause the increase of faults in defined position over the time. Those faults can be taken on vehicles that make short-term flights. In order to carry out longer-term military tasks, it is necessary to take periodic measures to correct the navigation system to reduce the number of faults caused by the INS as close to zero as possible. In addition, the appearance of lightweight and extreme lightweight flight apparatus has sharply hardened the weight-size requirements for the INS that has led to the renunciation of traditional INS. GPS offers a navigation system known for accurate operation all around the world. However, it is also known that the INS, which is well-known for its high quality and specific accuracy, at cheap prices, can perform almost all processes without the help of GPS [6, 7].

Obviously, the combination of both systems will enhance and correct each other, on increasing the reliability and accuracy of the navigation complex. Joint use of INS and GPS systems will lead to the resolution of a number of problems in the application navigation that requires the continuous information exchange. We will also examine the principles of the establishment of the INS and identify their available capabilities.

Inertial Navigation System (INS). The general requirements on the board equipment of flight apparatus are determined for the development of the science and technologies in the field of aviation navigation system [5]. These requirements directly come from strict requirements on the provision of flight safety for the civil aviation. One of the most important systems for the aviation is the INS. The essence of the inertial navigation consists of the determination of the acceleration of the object and its angular speed by the apparatus and equipment, installed on the moving object, the destination of the location (coordinates), course, speed, overcome way and other parameters of the object on the base of those data, as well as the destination of required parameters for the stabilization of the object and the control of its movement.

The creation of the navigation system with pilot and non-pilot flight apparatus is one of the most difficult problems, and the resolution of it fall on academicians, engineers and specialists, who are busied with tasks on the provision of flight. There are several methods for determining the flight coordinates and navigation parameters, such as flight speeds. These methods are divided into two categories: autonomous and non-autonomous. The inertial method that does not require the contact with the external system has best provided the autonomy. This method is based on the relationship known to mechanics between coordinates, the speed of the moving object and the acceleration.

The Inertial Navigation System consists of the inertial measuring module (IMU) or the inertial reference module (IRU) and the navigation determinants for the calculation of the freelance acceleration. Typically, the IMU consists of the three accelerometers and three gyroscopes [8]. The structural scheme of the inertial navigation system is shown in Figure 1. When accelerator measures the motion of the acceleration of the flight apparatus Earth's gravitation area also affect to its work. The navigation system on obtaining this value, i.e. freelance acceleration – g, from the measured value of the acceleration gives the real value.

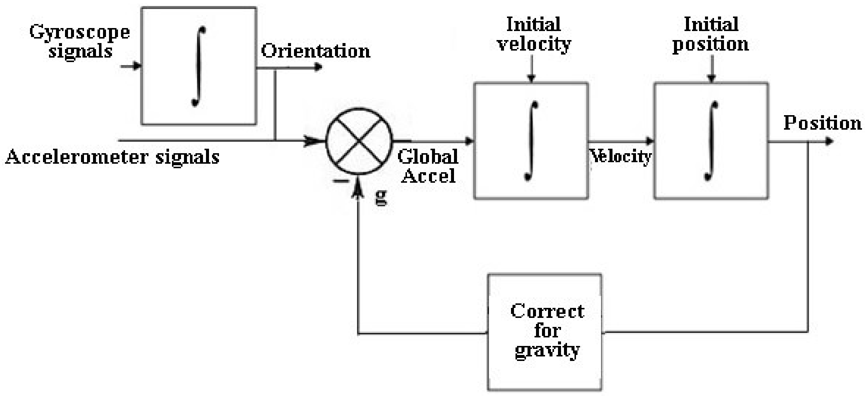

Fig. 1. The structural scheme of the inertial navigation system

Here the navigation system on integrating the signal from the gyroscope and on measuring the acceleration of object's movement in the moment by integration it 2 time destinies the coordinate. On the base of found coordinates there is determined the g value and deducted from the measured acceleration.

The main function of the INS is to calculate the acceleration and information on aircraft's roll, pitch and yaw angular and linear acceleration to send the required systems. This information is used for navigation calculation and roll-pitch displays [9].

The INS, which is used on civil aircraft, transmits navigational information to the necessary systems (FMS, EFIS, etc.). The system includes two or three IRUs. Each IRU has three laser gyroscope and three accelerometers. They also provide linear acceleration and angular speed respectively. The system calculates the navigation parameters by taking additional data from the Air Data Computer (ADC) and Flight Management Computer (FMC). System management is carried out with the help of the inertial reference mode panel (IRMP) [9, 10].

Generally, the inertial navigation system is divided into two groups:

- Gimbaled systems;
- Strap-down systems.

In gimbaled systems the support coordinate system is obtained by placing the gyroscope and accelerometers on the stabilized platform. Modern INS is mainly built without platform. Here, instantaneous) output signals of accelerometers are entered directly into the computer, and in the supporting coordinate system both instantaneous direction and the correction signals are calculated similar to this direction.

Gimbaled INS. The structure by the name Cardan suspension system is mechanical system. There are three accelerometers and gyroscopes, which are oriented towards freelance rotation axis, which are perpendicular to each other. In the center of the structure on the motionless board there are placed gyroscopes and accelerometers, which are able to measure in three directions. The structure of gimbaled INS has been shown in fig.2 [7, 11].

Gyroscopes on the fixed platform are used to determine any rotation moment. On the base of obtained information by the aim to provide the inact of the platform there are used servo-counter relation cycles.

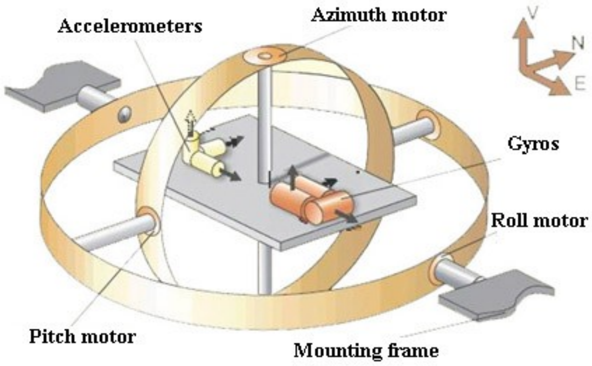

Fig. 2. Gimbaled INS

This type of the system has some deficiencies:

- the connection points are subjected to the friction;
- there is required a power to make the gimbaled system compatible with the navigation system;
- the calibration of the system is very difficult and it requires continuous technical service;
- the consumption of the energy is high, it has a large mass, a totality and it is expensive.

Strapdown INS. Strapdown INS has more simple construction than gimbaled INS system. In the strapdown inertial navigation equipment MEMS sensors of the general scheme construction have been placed on the steady frame in three directions to be able to measure (fig.3).

The strapdown INS is built on a moving object, consisting of 3 accelerometers, 3 gyroscopes, sensor's electronics and calculators, and has no mechanical action. There is no mechanical system in the strapdown construction, which prevents the mixing of the gravitational field intensity with the acceleration for the moving in accelerometers.

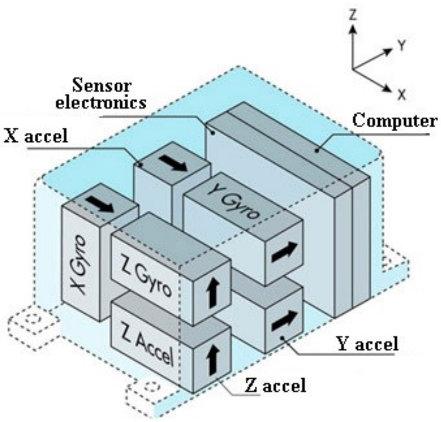

Fig. 3. Strapdown INS

The basic blocks, which are needed to build an unplanned IPS, can be separated (Fig.4) [11].

For the construction of strapdown INS it is possible to separate basic blocks, which are necessary (Fig.4) [11]:

- accelerometers block;
- gyroscopes block;
- calculation block;
- navigation algorithm;
- orientation algorithm.

The high speed of the measurements as a result of the development of electronics and microprocessor technique has enabled the transition to strapdown INS. In the strapdown navigation system, the calculation process is divided into two algorithms: the orientation algorithm and the navigation algorithm.

The navigation algorithm is intended to calculate the coordinates and speeds of the location of the object, and it additionally forms the absolute angular speed vector ug of the normal coordinate system.

Orientation algorithm is used to solve the orientation issue and to shape the C transitional matrix used in the calculation block. Orientation algorithm can be performed using different kinematic parameters like as Eyler-Krilov angles, oriented cosine, quaternion and so on [12].

It should be noted that strapdown INS has a number of advantages in composition with the gimbaled INS. First of all it has been widely used in recent years in terms of the lack of the gyro stabilized platform with a complex electromechanical device, its small size, low energy consumption and low cost production. In addition, the INS system and the general structure within it, can also be used in many military vehicles (submarines, tanks, etc.) or automation systems.

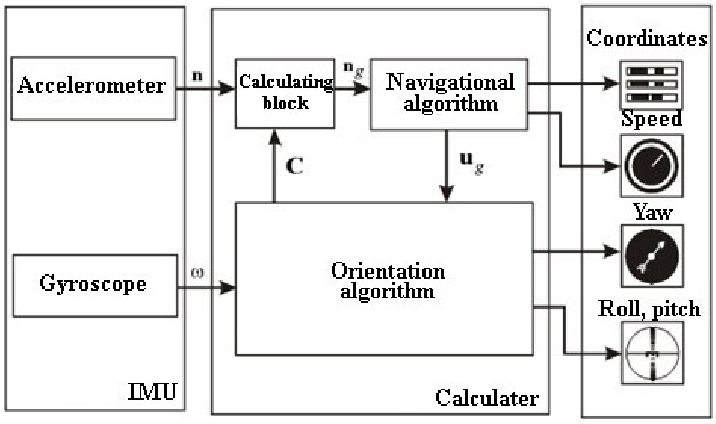

Fig. 4. Generalized functional scheme of the strapdown INS

Faults of inertial system. There are many fault sources in the INS for the absence of design standards in it [7]:

- reset faults, which are formed in the determination of initial values of the position and speed;
- initial directional times of gimbals or directional faults, formed from the cosine for the navigation axis of orientation direction in the strapdown system.
- compensation faults resulting from changes in the calibration or sensors over time;
- gravity model faults. For gyroscopes used in the inertial navigation, the fault patterns are mainly used for two purposes:

1. Determination of parameter functions of the gyroscope.
2. Calibration and compensation of any faults.

The main fault sources in the gyroscopes are zero drift, axis slopes, instant sensitivity and so on. But the main sources sources of faults for accelerometers are trends, the effects of freelance acceleration, the sensitivity of the angular acceleration and so on [8].

ISN model for unmanned aerial vehicles. In order to calculate the position on autonomous vehicles, firstly, values of the acceleration measured by the angle (Direction Cosine Matrix) matrices are used. The use of kinematic equations on the quaternion for the realization of above mentioned matter is the optimal way. The quaternion method is a very complex and highly effective method, developed by W.R.Hamilton for mathematical purposes. Such equations are linear and don't create any faults in the different positions of the object. Furthermore, the number of quaternion equation is 4, and they can be constructed using a contact equation [3, 12].

In the figure 5 there is presented INS model on the basis of MEMS sensors for small-size non-pilot flights. Here the angular condition of the aircraft from angular speeds, which are obtained from gyroscopes in the quaternion conversion, is calculated. On using obtained angular data the convergent matrix, from the aircraft support system, is found. This matrix is multiplied the measured acceleration in accelerometers. On counting the freelance acceleration from obtained values accelerations of the aircraft are obtained for the world support system. The speed and position of the aircraft are calculated by integrating the momentum in the global reference system. Moreover, gravitation must be calculated according to positional data, since the freelance acceleration is changed by coordinates and altitudes. The calculation of the gravitation according to WGS – 84 model (1984 World Geodetic System) in S system is also an important factor in terms of accuracy of measurements.

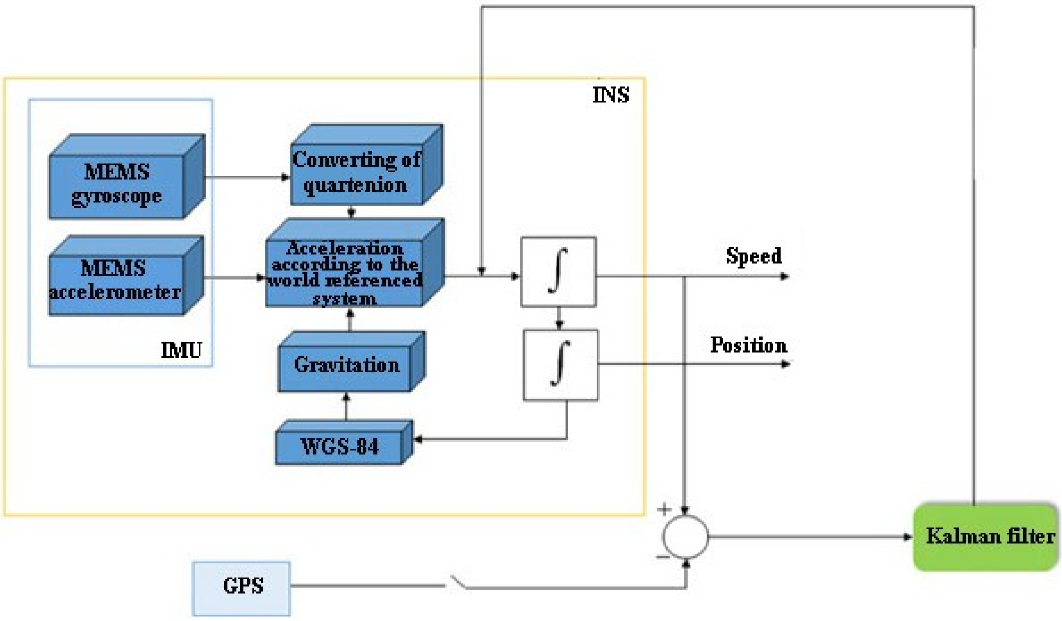

Fig. 5. INS model for unmanned aerial vehicles

As is known the Kalman filter has two models: system and observation model, and the fault is minimized in the model output. In this model the system model is consisted of the kinematic equations of the vehicles and the related situation variation. But support system or observation model, are navigation systems like as GPS and etc., which give the position, and speed information. If the PUA is given a special assignment to continue the flight without radio communications, the system may continue the flight simple only in accordance with the INS data on disassembling the GPS (microelectromechanical). In this case the INS must be screened specifically to avoid external influences. Because of the high frequency of measurements from the INS in terms of indirect calculation the load is great. Direct and indirect counter relation methods may be used. In these methods estimated position are fault values. The difference between the measurements of the INS and auxiliary navigational systems is used in the observation model as an observed fault. In the same way, the system model incorporates the modeling of the faults with inertial navigation equations. The lack of the indirect counter relation filters is an infinite increase in fault values. Therefore, as the most optimal variant, we have used a direct counter relation method. On using this type of counter relation combinations it is possible to minimize the increasing of observed fault values. The sensitivity and precision of the measuring results of INS, which are used in many vehicles, ranging from PUA to underwater boats, are made this system more demanding, especially when there are no GPS signals. In addition the simplicity of the calculation, as the algorithm used to find the position, will be repeated at a high frequency, the closing time of the system will be reduced to a considerable extent.

Conclusion. The optimal modeling and research of INS, which is lasting against obstacleson the base of micromechanical sensors, can help to develop high-tech defense system, that can be used also as soon as possible to reduce the dependence on external influence. In the work there are researched the construction principles of inertial navigation system, perspective directions of the development are determined, and are proposed the model of the inertial navigation system on the base of MEMS sensors with optimized parameters for small-sized unmanned aerial vehicles. Because of the use of the GPS and Kalman filter in the model, the increase in the value of the fault is minimized. The main advantages of the proposed INS model are autonomy, universality, durability to obstruction and precision.

References

1. Timoşenkov S. P. Primenenie MGMS - sensorov v sistemax naviqatsii i orientasii podvijnıx obyektov / S.P. Timoşenkov, A.P. Kulgchiukiy // İzvestiя vuzov. Elektronika. 2012. - №6 .– S.51-56.
2. George T. Schmidt. INS/GPS Technology Trend. Advances in Navigation Sensors and Integration Technology, Published February 2004. ISBN 92-837-1114-9
3. E. Bushdok, A.E. Ozchelik “İnersiyal navigasyon sistemleri”. Uzaktan Algılama ve Cografi Bilgi Sistemleri Sempozyumu UZAL-CBS 2008, Kayseri. Seh. 585-594.
4. Nabiyev R.N., A.Z. Mammadov. Mikroelektromekhaniki akselerometr ve giroskopların parametrlerinin muqayiseli tahlili. Azerbaycan Muhandislik Akademiyasının Khaberleri, Bakı-2018, №3, Cild10. seh. 7-20.
5. Stepanov O.A. Osobennosti postroeniya i perspektivı razvitiya naviqatsionnıx inertsialno-sputnikovıx sistem. /İnteqrirovannıe inertsialno-sputnikovıe sistemı naviqatsii. Sb. statey dokl. SPb. 2001.
6. KEVIN J. WALCHKO, “Low cost Inertial Navigation: Learning to Integrate Noise and Find Your Way” A Thesis Presented to The Graduate School of The University Of Florida in Partial Fulfillment of The Requirements For The Degree of Master of Science (2002).
7. Ozchelik A.E., 2009. “Kalman Filtrleme Yontemi kullanılaraq GPS/İNS Veri Entegrasyonu”, Yüksek Lisans Tezi, Erciyes Universitesi Fen Bilimleri Enstitusu, Kayseri.
8. A.Z.Badalov, R.N.Nabiyev, A.Z.Mammadov “Uchush aparatlarının shaquli suretlerinin olchulmesinin hususiyyetleri”. Monoqrafiya. Bakı, MAA, 2018, 208 seh.
9. A.Z.Badalov, R.N.Nabiyev, A.Z.Mammadov “Aviasiya cihazları və informasiya-olchme sistemleri”. Derslik. Bakı, MAA, 2017, 382 seh.
10. Boeing 767 Maintenance Training Manual. Navigation Systems. 2012.
11. T.C. Milli Egitim Bakanlıqı, Uçak Bakım., Modul “Digital Uçak Sistemleri”. Ankara-2011, 80 seh.
12. Matveev V.V. İnertsialnıe naviqatsionnıe sistemı: Uchebnoe posobie. İzd –vo TulQU, 2012.-199 s.